Analysis of Fuel Cell Powertrain Implications Using ADVISOR

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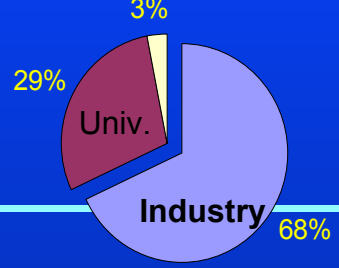
Outline

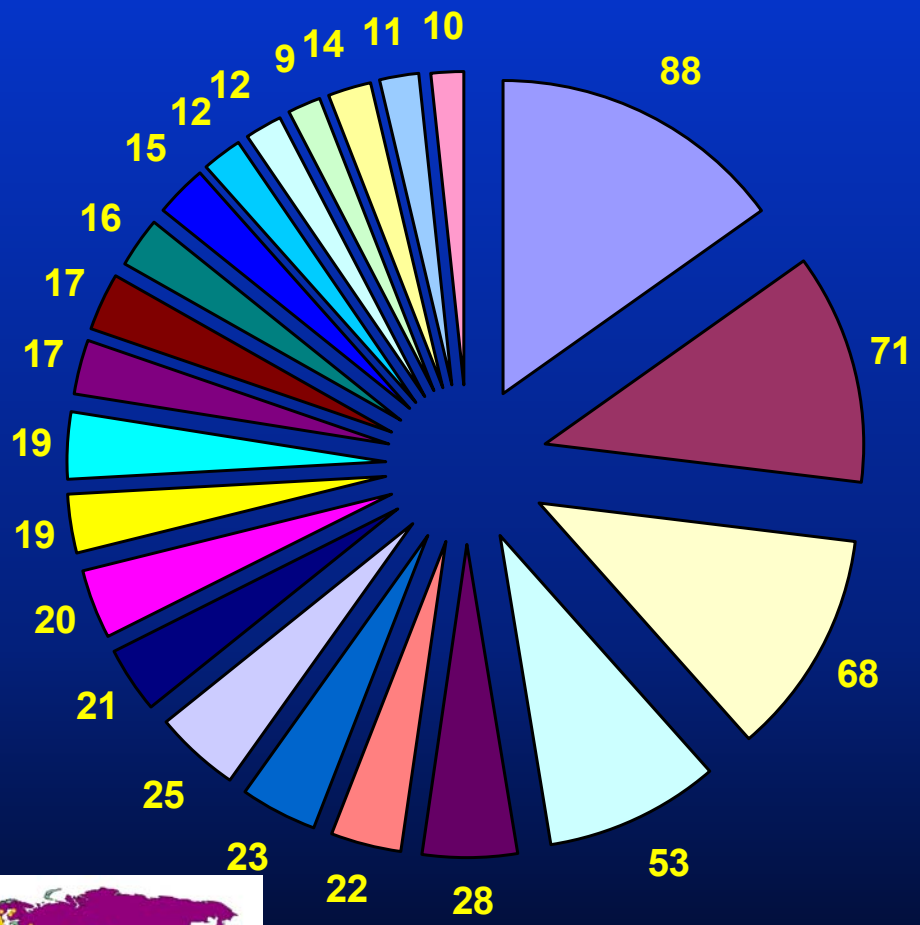
- Background on ADVISOR
- Fuel Cell System Model Overview
- Definition of Water Balance
- Vehicle Specifications
- Results from Simulations
- Conclusions

Background on ADVISOR

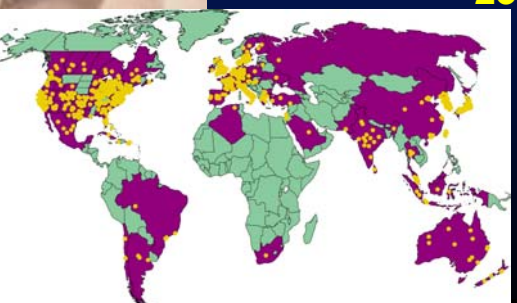
- ADVISOR = **AD**vanced **V**eh**I**cle **S**imulat**OR**
  - simulates conventional, electric, or hybrid vehicles (series, parallel, or fuel cell)
- ADVISOR was created in 1994 at NREL to support DOE Hybrid Program
- Distributed on web by NREL from 1994-2002
- Downloaded by over 7000 people around world
- Held 2 ADVISOR User Conferences
- In 2003, ADVISOR licensed to AVL for commercial release

2/3 of Users are from Industry, All Major Auto OEMs & Suppliers





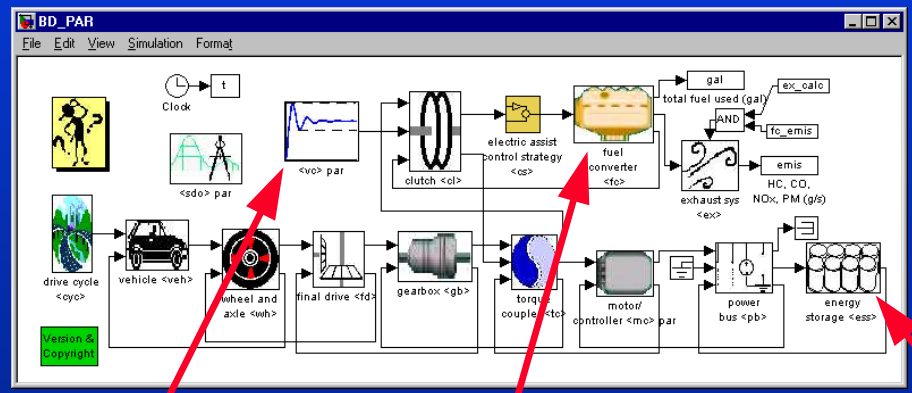
- Ford Motor Company
- Visteon
- DaimlerChrysler Corporation
- General Motors
- Delphi
- Volvo
- Siemens Automotive Systems
- Ricardo, Inc.
- Hyundai Motor Company
- Honda
- Hitachi Ltd.
- Fiat
- Eaton Corporation
- Nissan Motor Company
- Mathworks
- FEV Engine Technology
- Renault
- Mitsubishi Motors Corporation
- Flowmaster
- AVL
- Denso Corporation
- Allison Transmission



Legend includes organizations with 8 or more users since v2.0

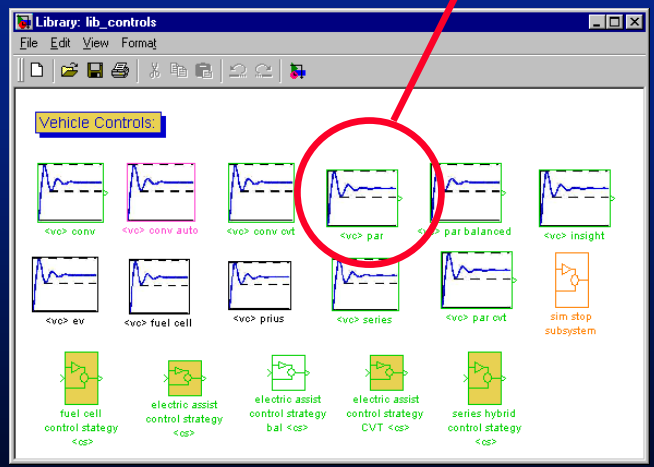
As of 9/20/02

Basic Structure (models) In the Matlab/Simulink Environment

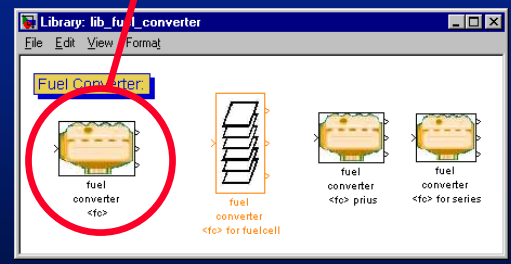


Block Diagram

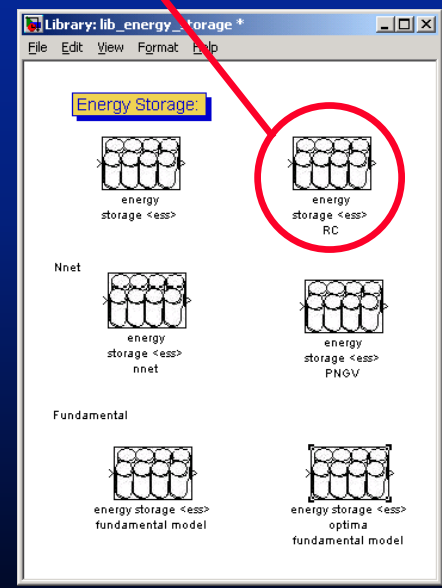
Control



Engine



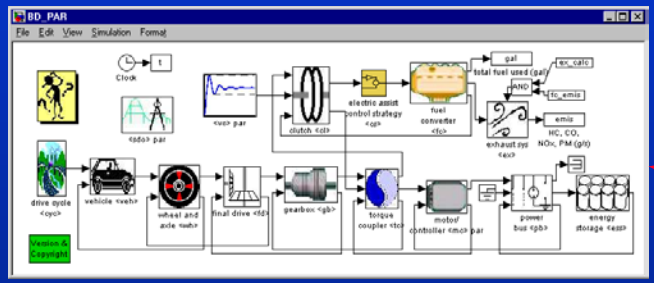
Battery



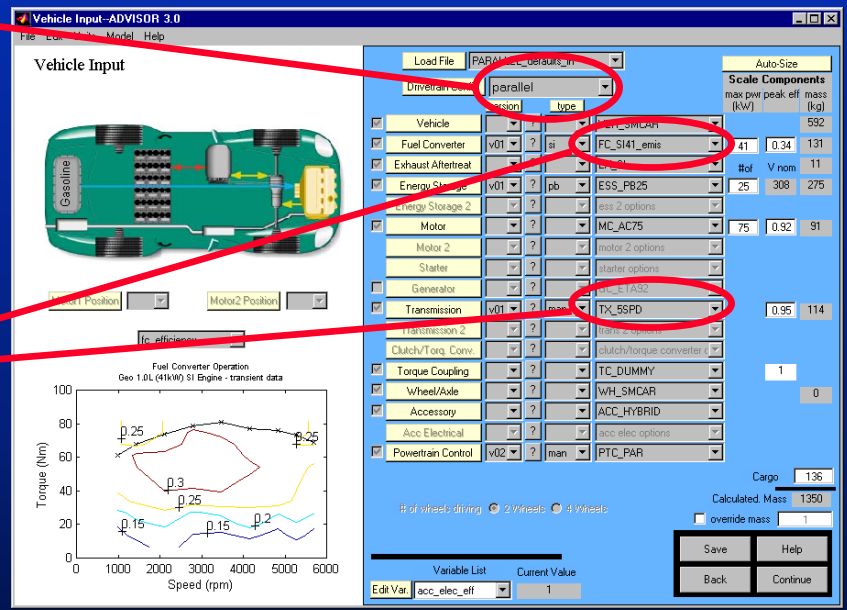
Libraries

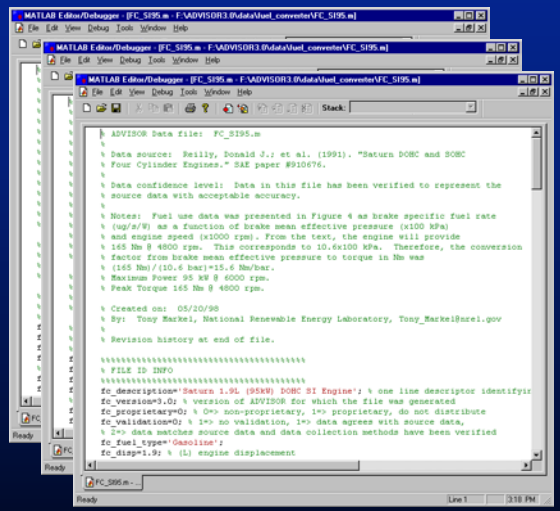
Basic Structure (database)
How the Data/Models are Pulled into the GUI

Block Diagram



GUI

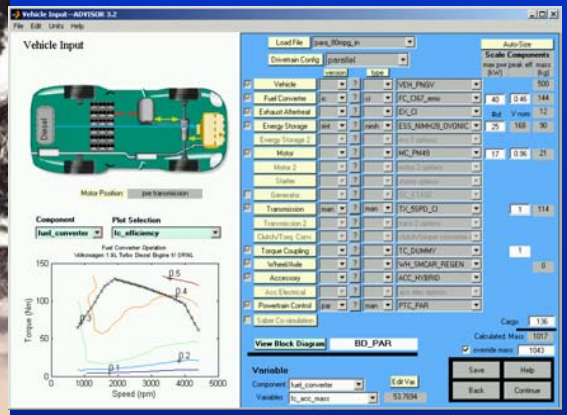




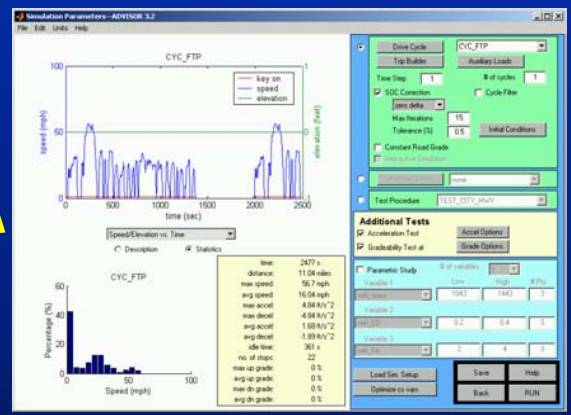
Data Files

Three Main ADVISOR GUI Screens

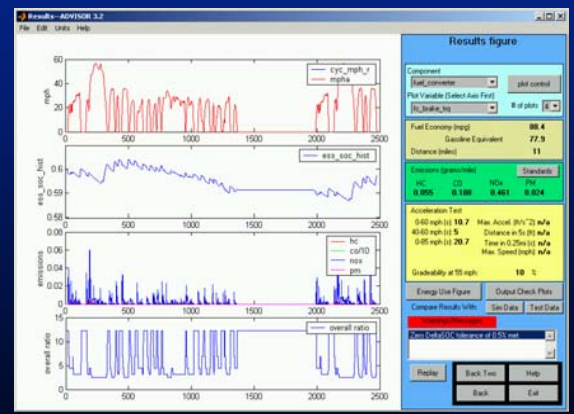
Vehicle Input



Simulation Setup



Results



Range of Fuel Cell Model Complexity in ADVISOR

More Detail

*** User-defined model ***
- configurable subsystem structure
- ability to link to fuel cell models in other tools (e.g. Saber, Simplorer,…)

Model 2
- Springer et. al. fuel cell model
- thermodynamic library
- balance of plant components
- water transport in MEA

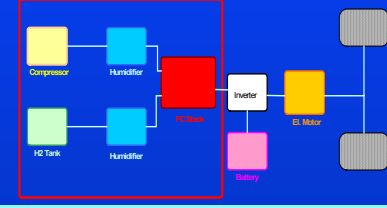
Model 1
- parametric polarization curve
- system thermal model
- balance of plant components
- variable operating pressure

Less Detail

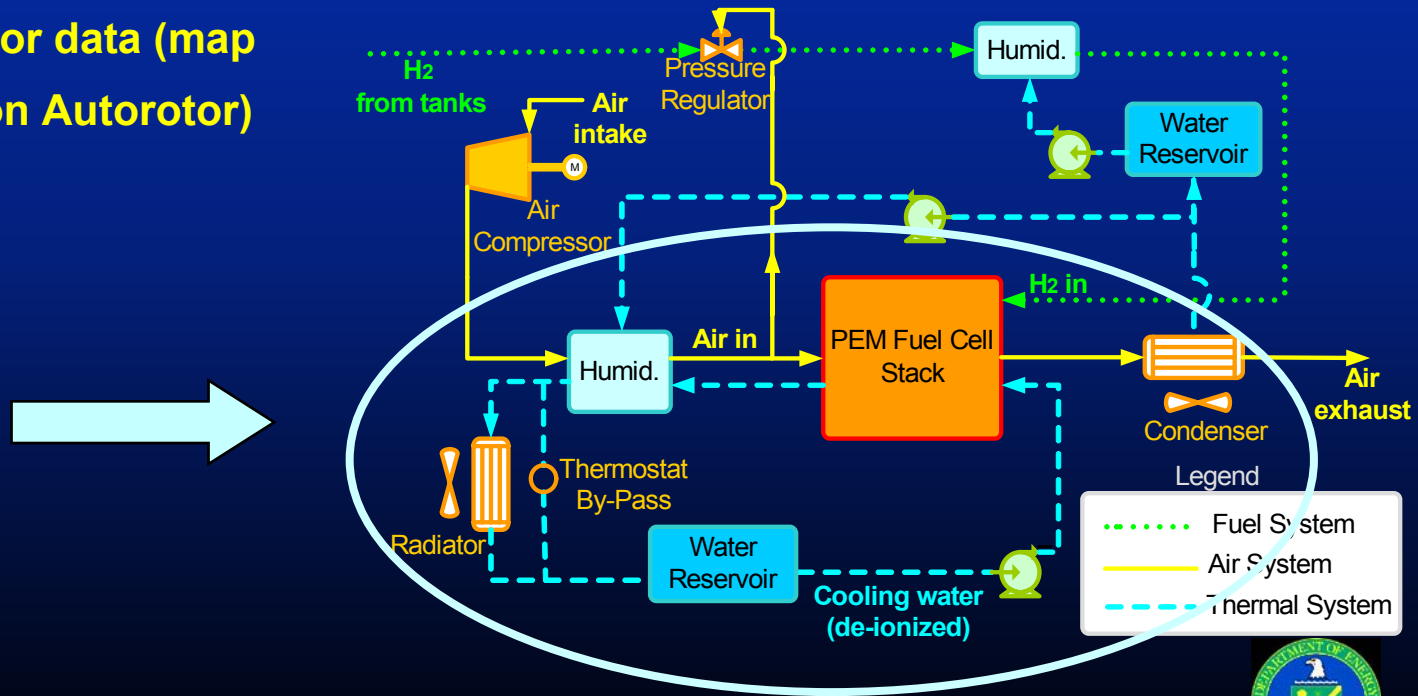
Simple Polarization Curve
- defined current and voltage
- simplified balance of plant

Net Power vs. Efficiency
- single curve
- scalability

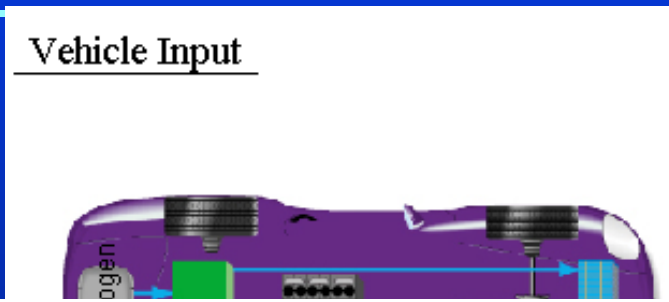
Model 1
Fuel Cell System Model Used for Study

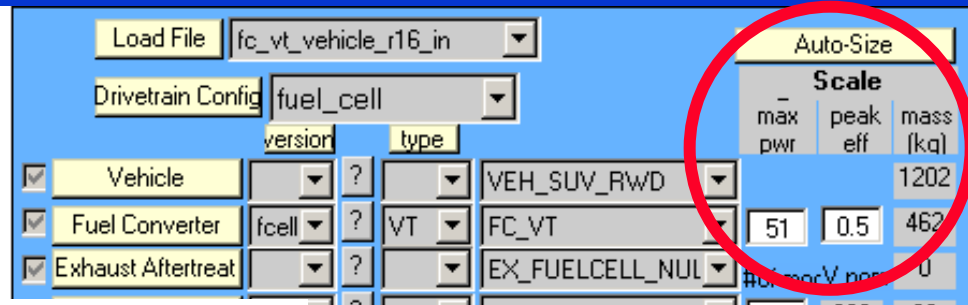


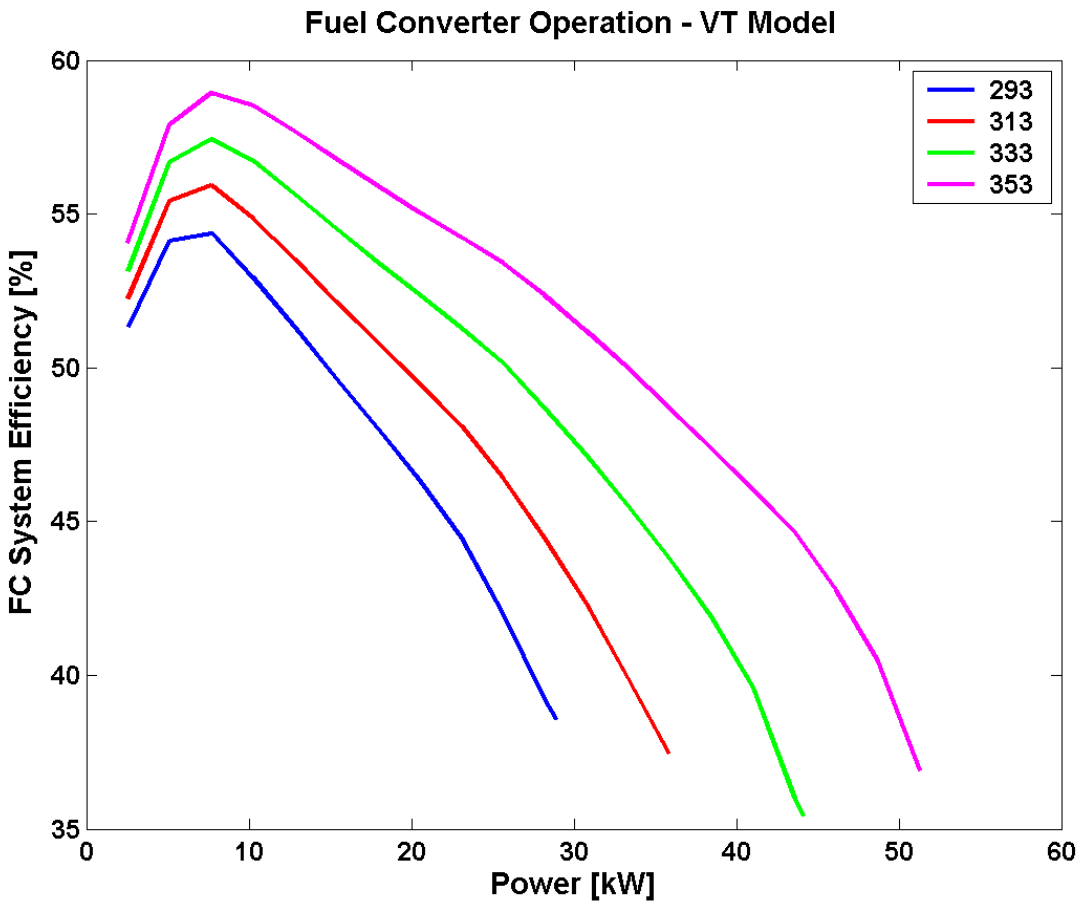
- Semi-empirical, transient
- Thermal model for ADVISOR to evaluate:
  - –Hot & cold start vehicle fuel economy
  - –Power limitations due to temperature
  - –Water balance for reactant humidification
- Polarization curve based on Honeywell stack
- Compressor data (map from Opcon Autorotor)



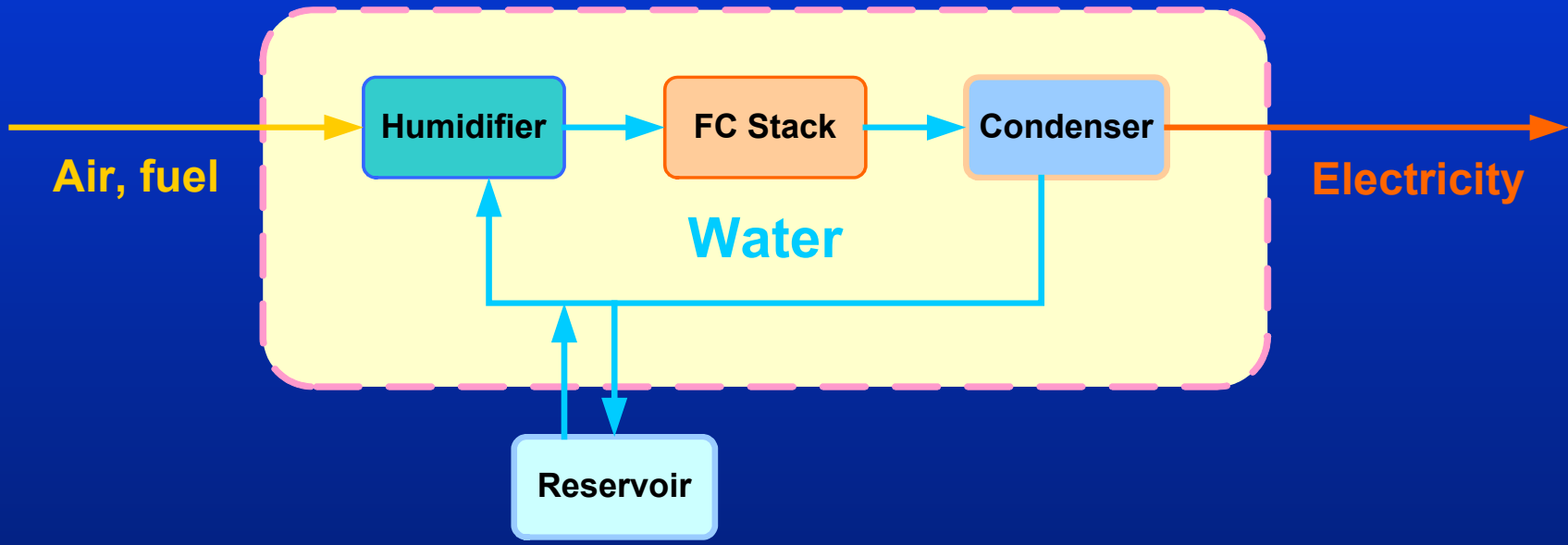
Example of ADVISOR Input: the FC Model







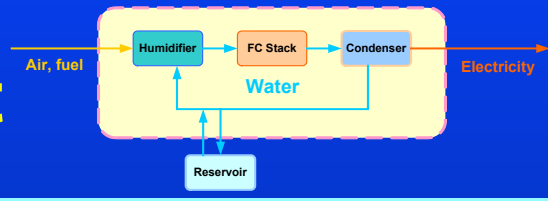
Definition of Water Balance



- Neutral water balance:

Water needed for humidification	=	Water produced at the cathode	+	Water condensed out of the exhaust

FC Vehicle Design Requirement



- Under no conditions have water deficiency

Condenser or water reservoir **size**

needs to be large enough

for both **cold** and **hot** start conditions in drive cycles

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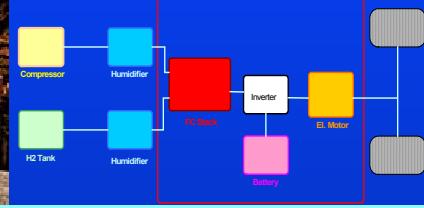
In this study we varied:

- System parameters
  - – condenser size, rel. humidity requirements of the cathode inlet gas, ambient pressure (elevation)
- Vehicle parameters
  - – cold and hot start, drive cycles

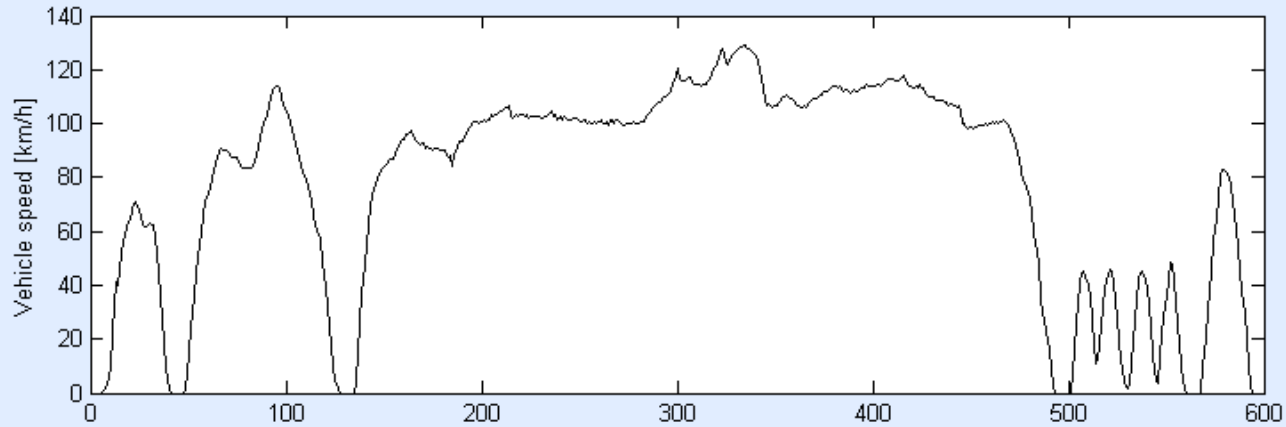
Baseline Components

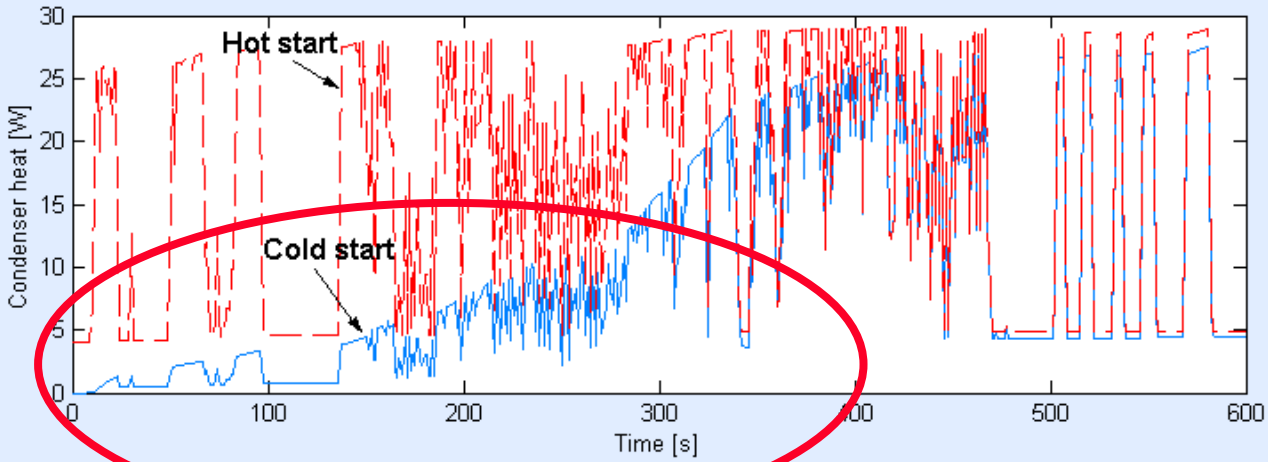


Based on
a mid-size SUV similar to Jeep Grand Cherokee

Component	Description
Fuel Converter	50 kW pressurized fuel cell system, Virginia Tech
Motor/Controller	117 kW AC induction motor developed by Virginia Power Technologies
Energy Storage System	12 Ah Li-ion battery pack

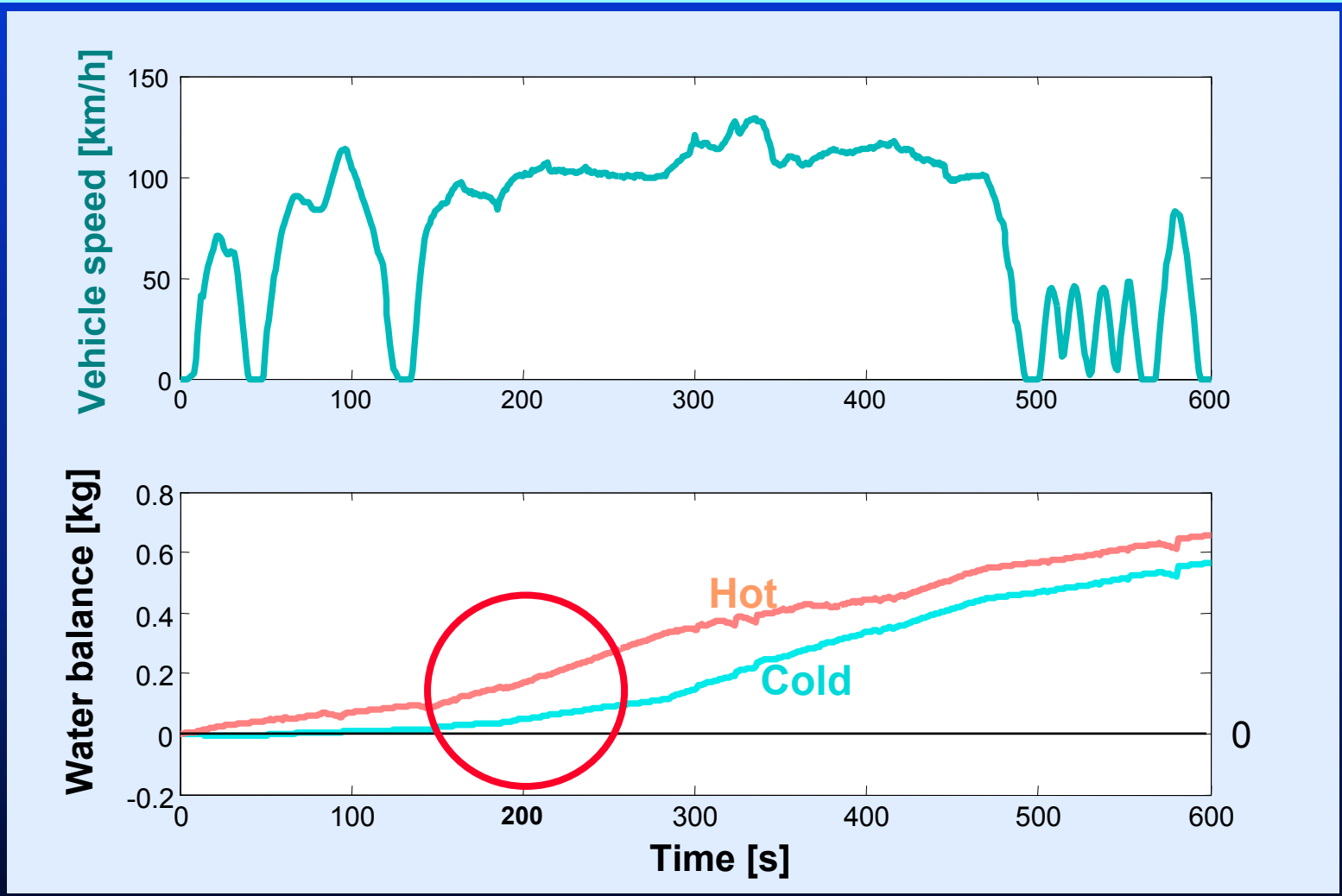
Example of Heat Rejected In Condenser During Cold and Hot Start in an Aggressive Cycle (US06)





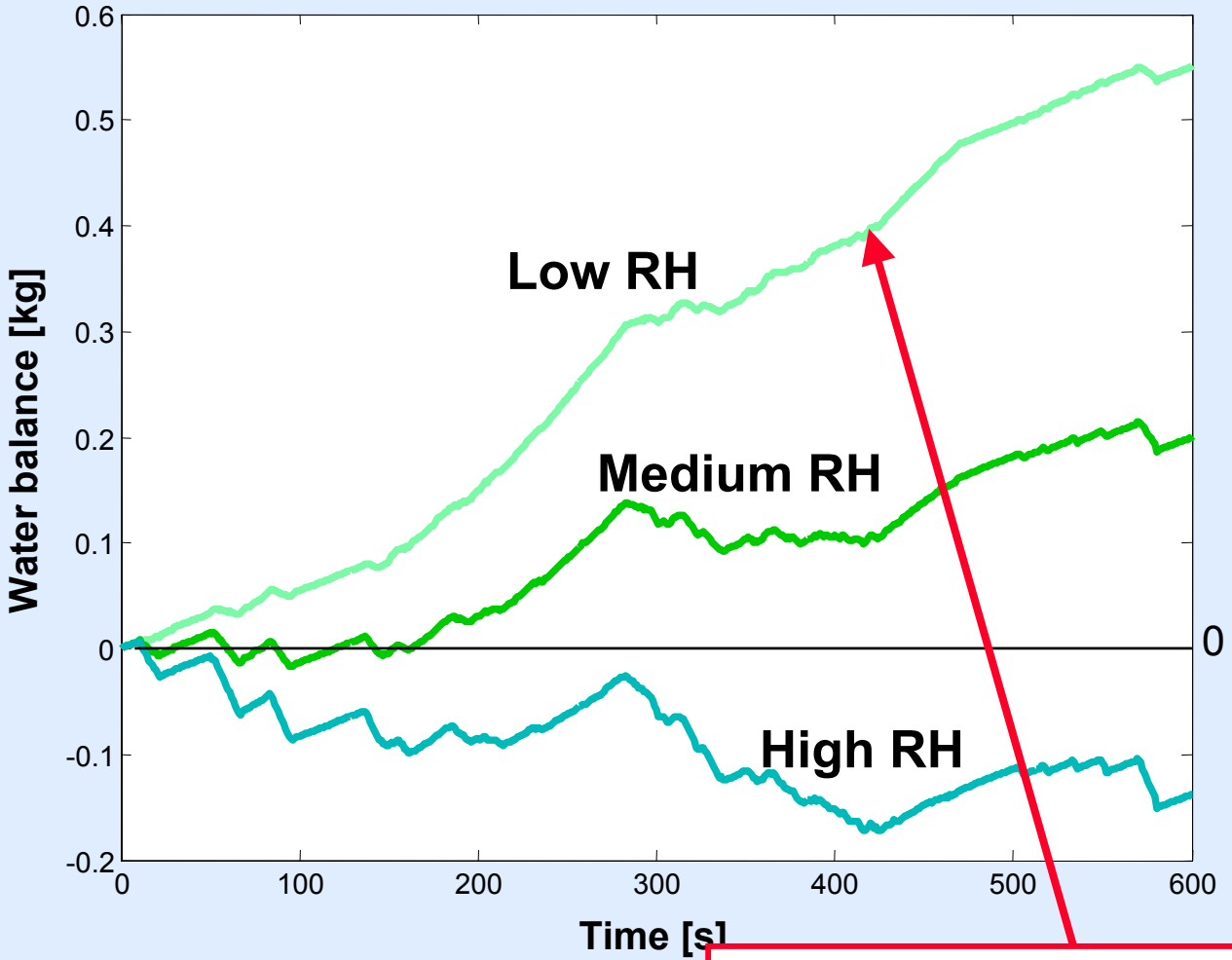
Cold start:
takes up to 400s to reach full functionality of the condenser

Example of Evaluating Water Balance on US06 for Hot vs. Cold Start



Cold start: water balance positive as condenser begins to become effective

Water Balance Sensitivity to the Cathode *Inlet Humidity* Requirements

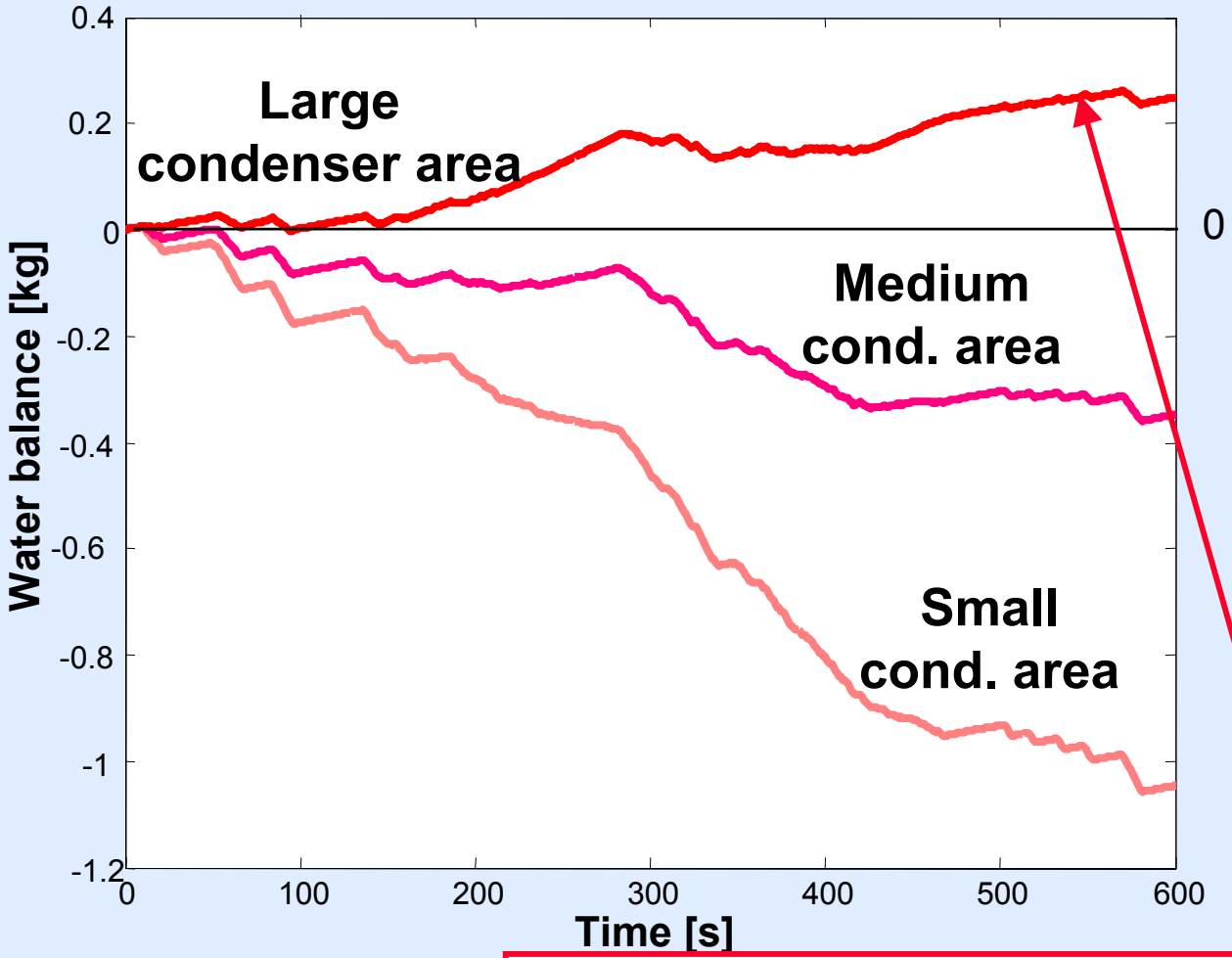


US06
Hot start

One reason for significant research in high-temperature membranes

Positive water balance at low relative humidity requirements, RH=30%

Water Balance Sensitivity to the *Condenser Area* (US06 cycle)

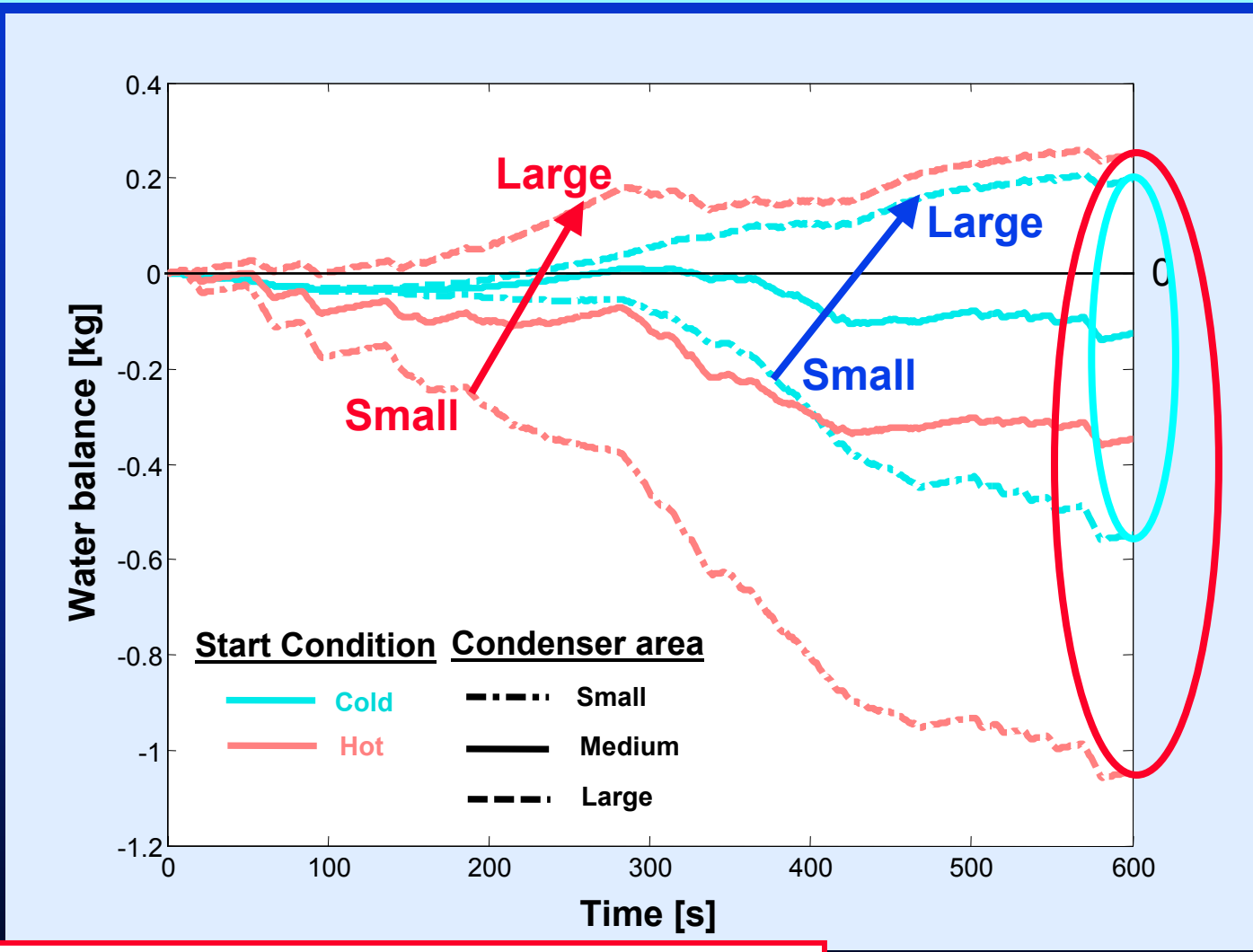


US06 Hot start

Higher temperature membranes would also help decrease condenser area requirements

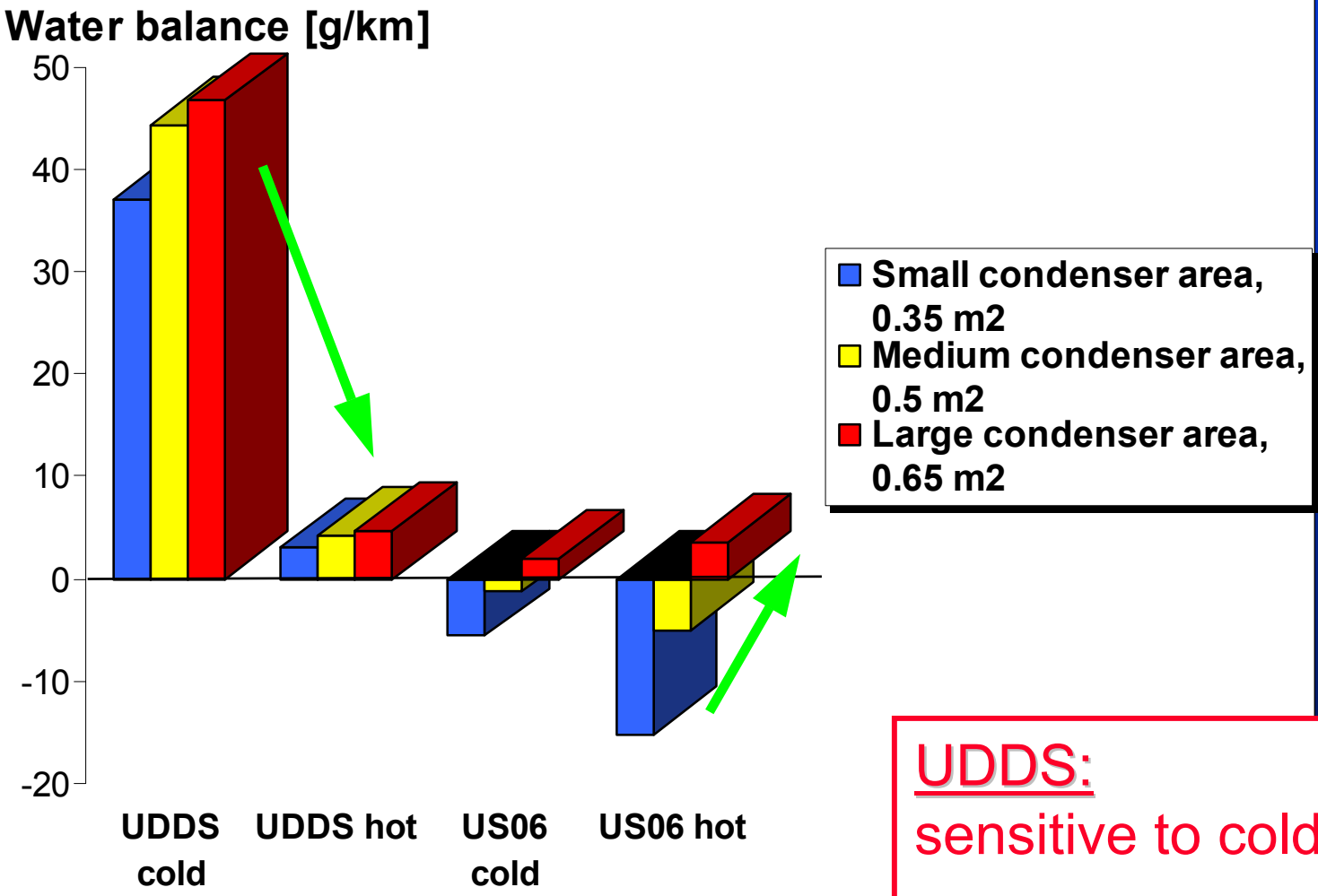
Relatively large condenser area required for positive water balance on hot US06 (0.65 $m^{2)}$

Sensitivity of the Condenser Area for Cold & Hot Start (US06 Cycle)



Lower water balance sensitivity to condenser area at cold start than hot start

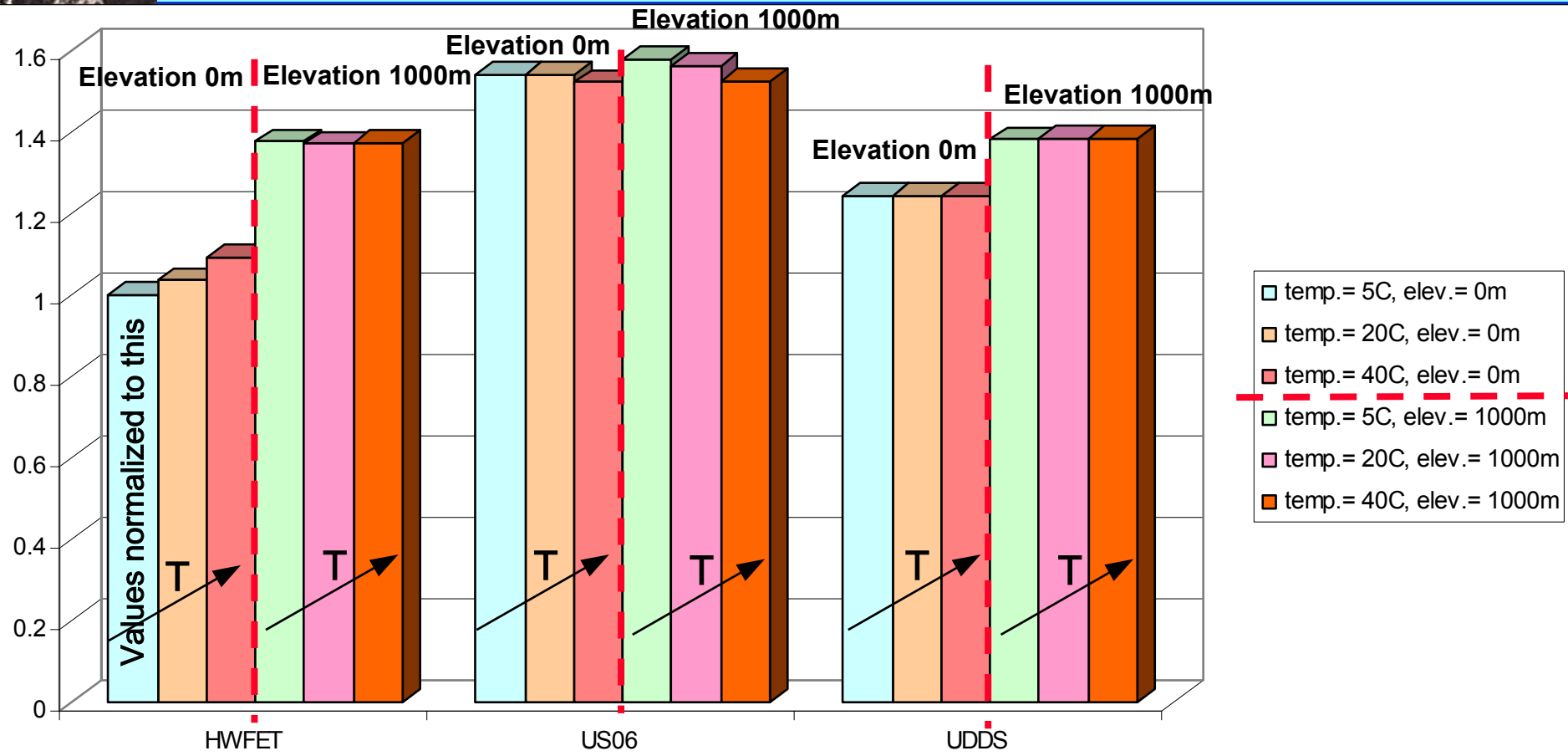
Cold/Hot Start and Condenser Area Sensitivities Different on 2 Cycles: UDDS and US06 Cycles



UDDS:
sensitive to cold/hot start

US06:
sensitive to size of condenser

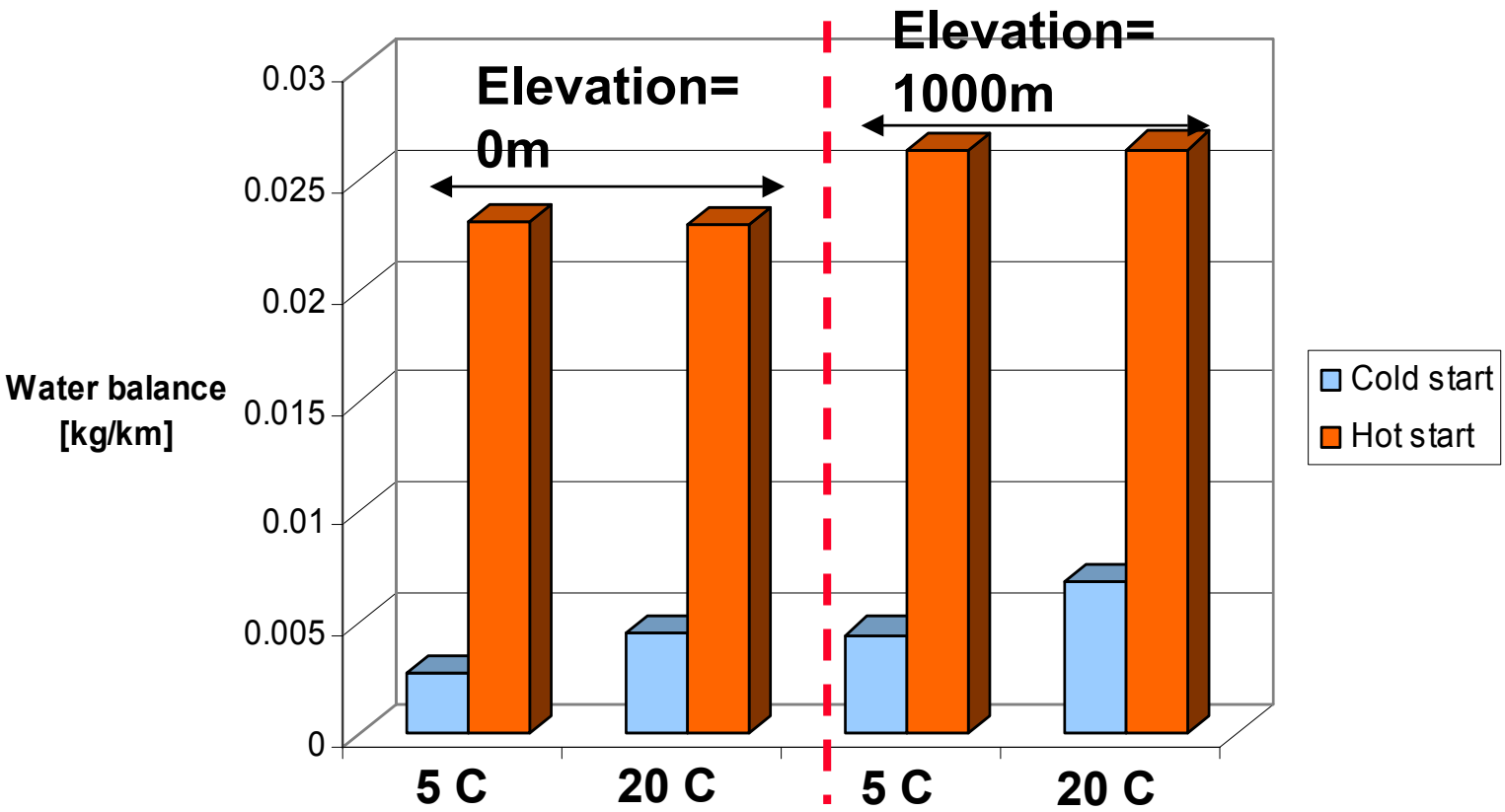
Maximum *Heat Generated/Rejected* at Different Ambient Pressures (Elevation), Temperatures, and Drive Cycles



Values are normalized with respect to the 5c, 0m HWFET case. Ambient conditions: RH=30%.

Ambient pressure (elevation) has larger effect on stack heat generation than ambient temperature, but it *depends on the drive cycle*

Water Balance Affected By Ambient Pressure and Temperature (HWFET Cycle)

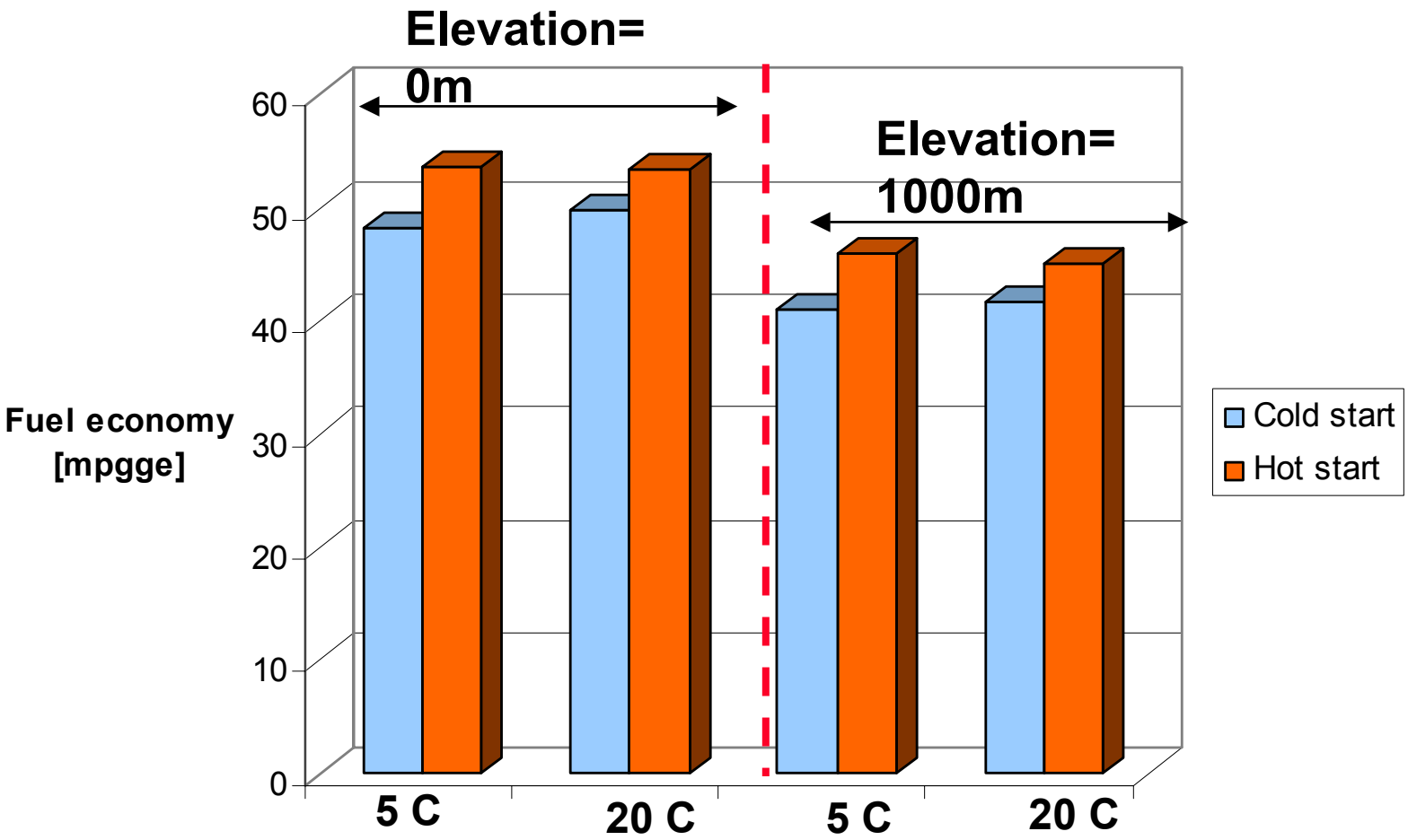


+ water balance indicates excess water

RH= 75%

Water balance improves (~14%) at higher elevation.

Fuel Economy Decreases with Elevation and Cold Start (HWFET Cycle)



Fuel economy is reduced (~15%) at higher elevation

RH= 75%

Conclusions

- Demonstrated ADVISOR fuel cell hybrid vehicle simulation tool with thermal and transient properties
- Drive Cycle: Aggressive (US06)
  - water balance more sensitive to condenser area than cold/hot start
  - need a large condenser to ensure positive water balance for both cold and hot start conditions
  - *or*, if a small condenser is used, a large water reservoir will be necessary
- Drive Cycle: Moderate (UDDS)
  - water balance more sensitive to cold/hot start than condenser area

Conclusions (cont.)

- Important to look on the water balance during the **entire** cycle rather than just the average value
  - However, properly sized H20 reservoir balances out swings
- Water balance is favored by low relative humidity requirements of the cathode inlet gas
  - Supports development of high-temp membranes
- Ambient pressure (elevation) has a larger effect on stack heat generation than ambient temperature
- Water balance improves by ~14% at higher elevation for highway driving
- Fuel economy reduced by ~15% at higher elevation for highway driving